



US009257616B2

(12) **United States Patent**
Harvey et al.

(10) **Patent No.:** **US 9,257,616 B2**
(45) **Date of Patent:** **Feb. 9, 2016**

(54) **MOLDED LED PACKAGE AND METHOD OF MAKING SAME**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(21) Appl. No.: **14/465,947**

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(22) Filed: **Aug. 22, 2014**

Harvey, D. et al., "Molded LED Package," U.S. Appl. No. 14/031,829, filed Sep. 19, 2013.

(65) **Prior Publication Data**

(Continued)

US 2015/0060903 A1 Mar. 5, 2015

Related U.S. Application Data

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Assistant Examiner — Tyler Drye

(60) Provisional application No. 61/870,312, filed on Aug. 27, 2013, provisional application No. 61/870,323, filed on Aug. 27, 2013, provisional application No. 61/969,629, filed on Mar. 24, 2014.

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(51) **Int. Cl.**

H01L 33/62 (2010.01)

H01L 33/48 (2010.01)

H01L 23/00 (2006.01)

(Continued)

(57) **ABSTRACT**

Packaged light emitting diodes (LEDs) and methods of packaging a LED include providing a first lead having a first recess in a bottom surface and a second lead having a second recess in a bottom surface, placing a LED die over a top surface of at least one of the first and the second leads, electrically connecting the LED die to the first lead and to the second lead, forming a package around the LED die that includes an opening in its upper surface exposing at least the LED die, and separating the package containing the LED die, the first lead and the second lead from a lead frame such that the package contains a first castellation and a second castellation in a side surface of the package, such that the castellations expose the leads and/or a first platable metal which is electrically connected to the leads.

(52) **U.S. Cl.**

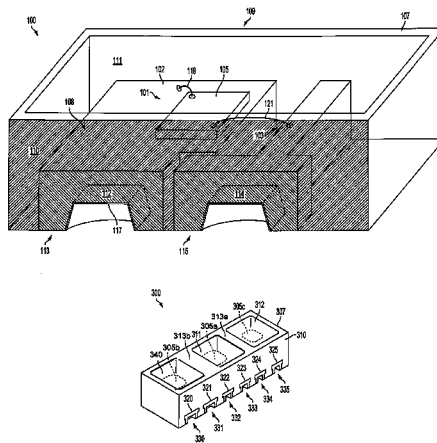
CPC **H01L 33/486** (2013.01); **H01L 24/97** (2013.01); **H01L 25/0753** (2013.01); **H01L 33/504** (2013.01); **H01L 33/62** (2013.01); **H01L 2224/48091** (2013.01); **H01L 2224/48247** (2013.01); **H01L 2224/48257** (2013.01); **H01L 2933/0033** (2013.01); **H01L 2933/0066** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

16 Claims, 8 Drawing Sheets



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Notice of Allowance and Fee(s) Due mailed May 26, 2015, for U.S. Appl. No. 14/031,829, filed Sep. 19, 2013.

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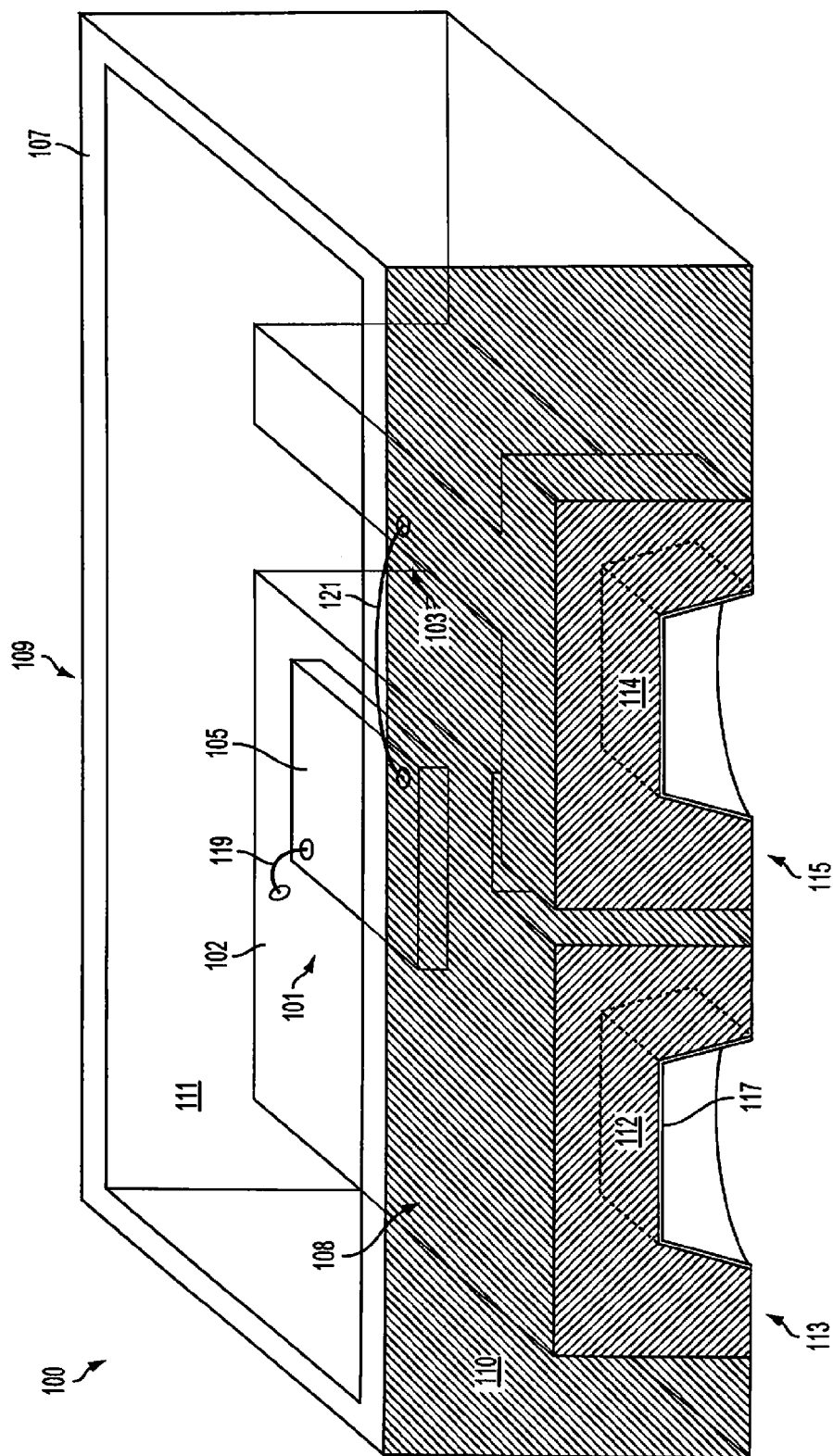


FIG. 1

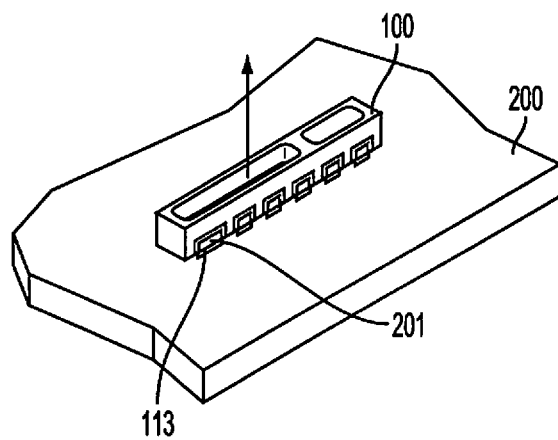


FIG. 2A

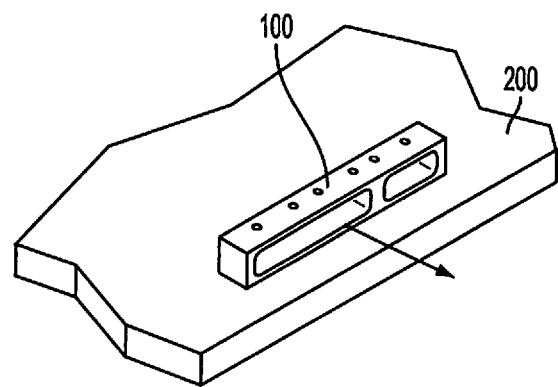


FIG. 2B

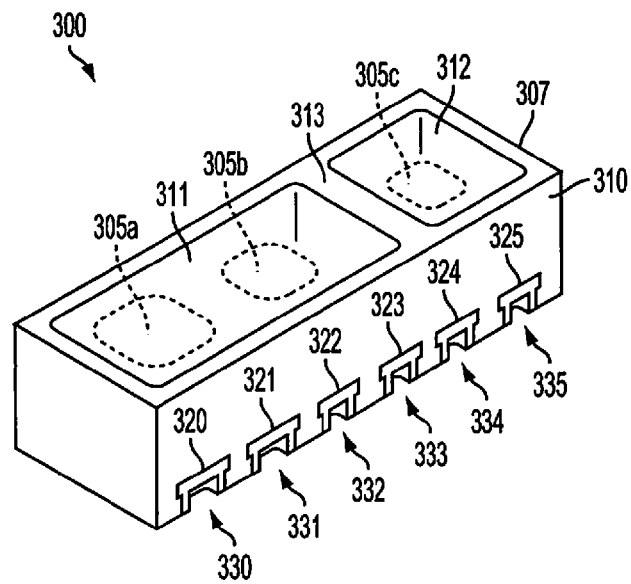


FIG. 3A

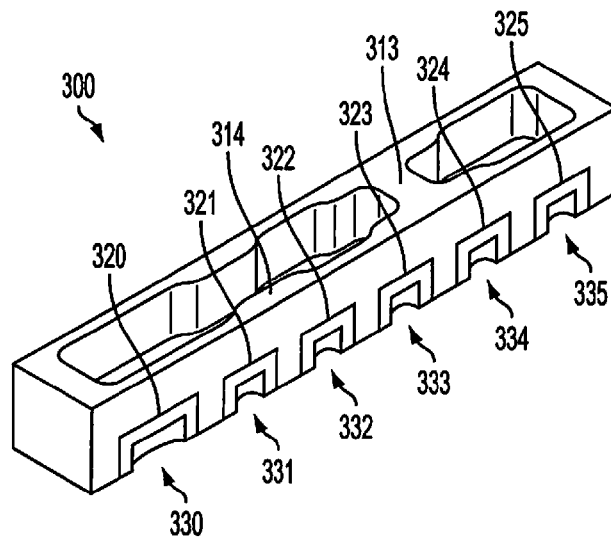


FIG. 3B

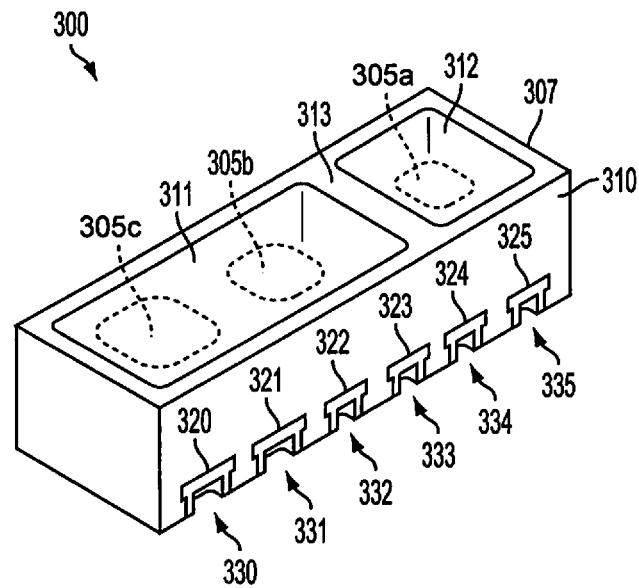


FIG. 3C

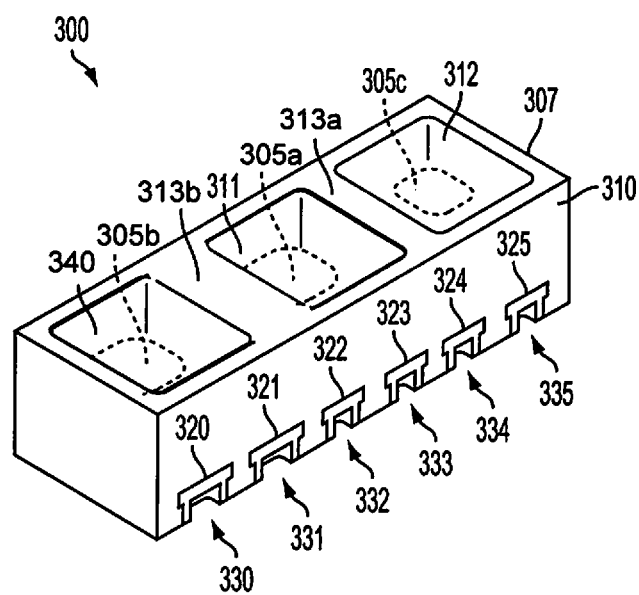


FIG. 3D

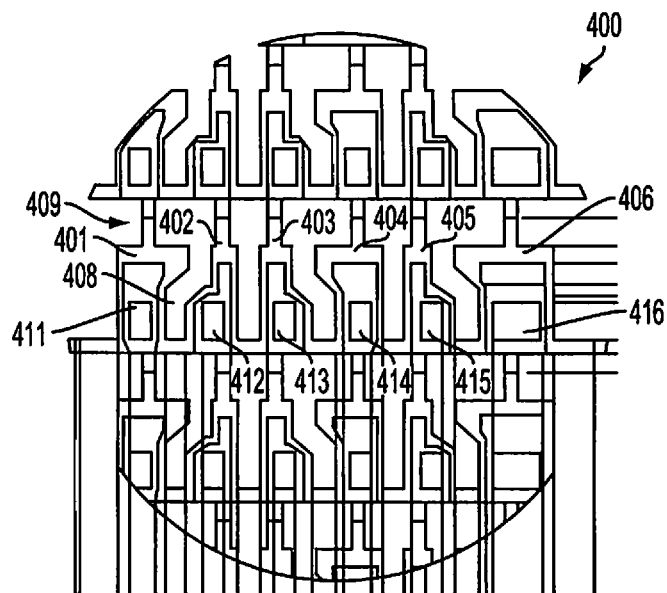


FIG. 4A

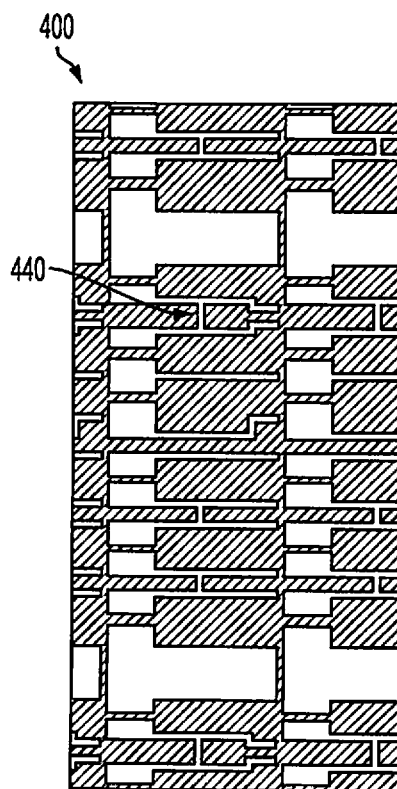


FIG. 4B

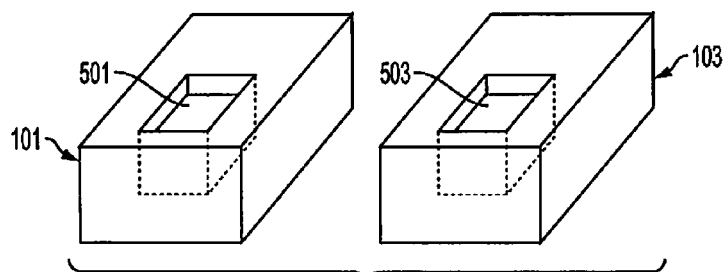


FIG. 5A

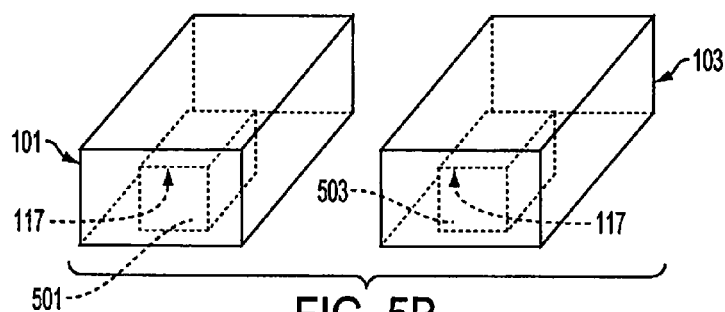


FIG. 5B

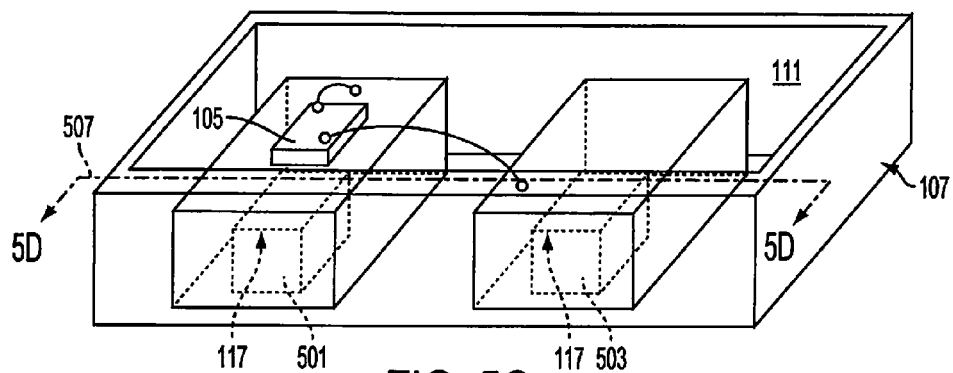


FIG. 5C

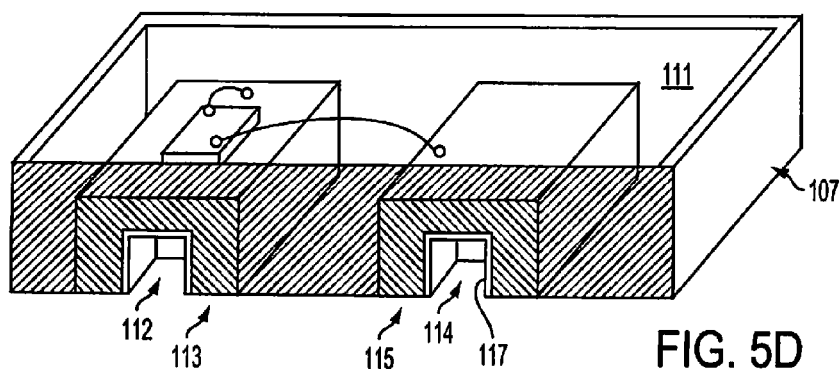


FIG. 5D

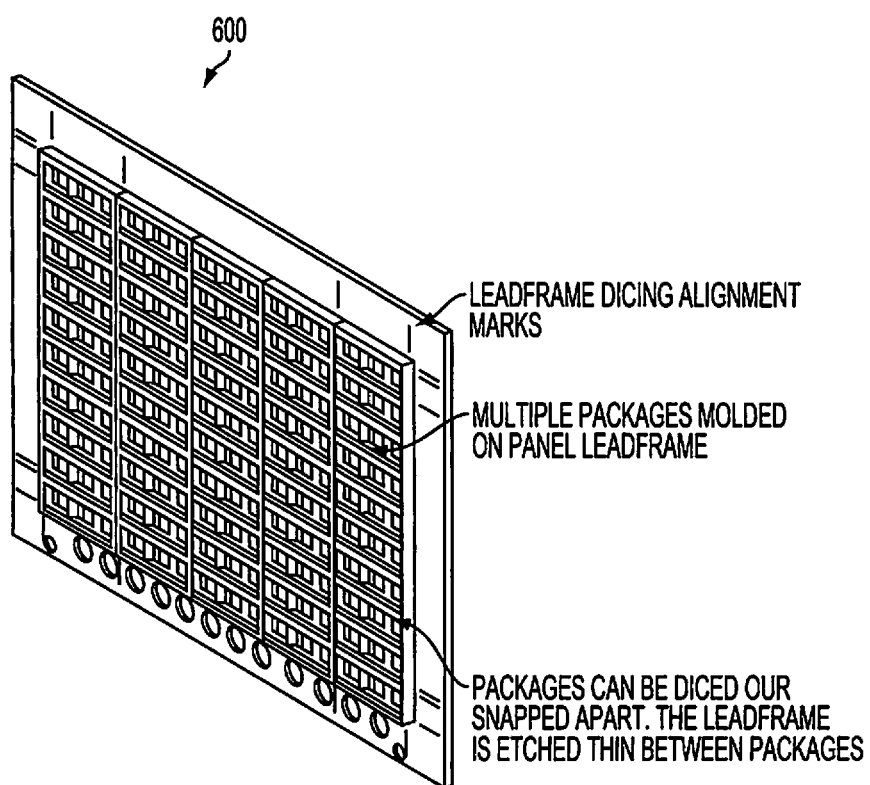


FIG. 6

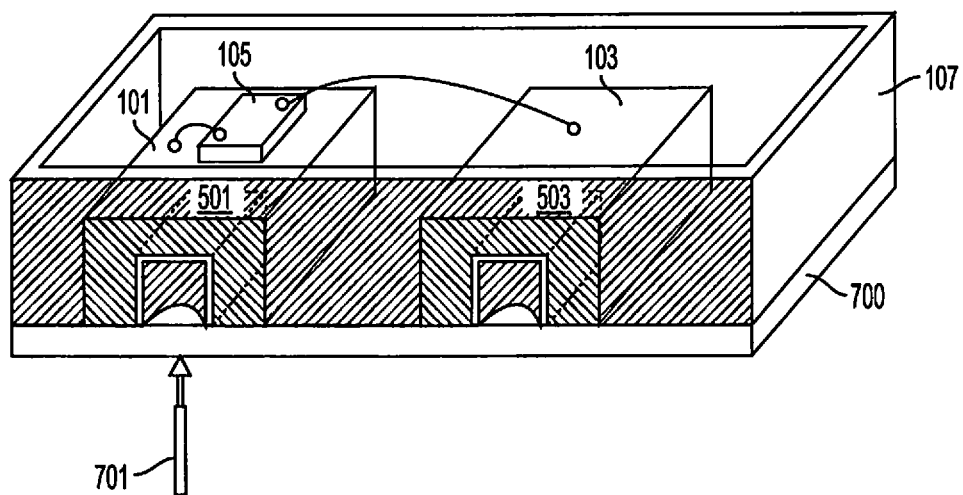


FIG. 7

1

MOLDED LED PACKAGE AND METHOD OF MAKING SAME

RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application Nos. 61/870,312, filed Aug. 27, 2013, 61/870,323, filed Aug. 27, 2013, and 61/969,629, filed Mar. 24, 2014, the entire contents of all of which are incorporated herein by reference.

FIELD

The embodiments of the invention are directed generally to packaged light emitting diode (LED) devices and methods of packaging LED devices.

BACKGROUND

Light emitting diodes (LEDs), such as nanowire LEDs, have a variety of uses, including in electronic displays, such as liquid crystal displays in laptops or LED televisions. In a typical LED packaging process, a semiconductor die containing one or more LEDs is mounted to a lead frame, and the die and lead frame are encased in a protective mold. The mold may include an open region aligned with the LED that enables light to be emitted from the LED. Electrical connections to the LED package may be made via the lead frame. Further improvements in LED packaging would be desirable.

SUMMARY

Various embodiments include methods of packaging a light emitting diode (LED) that include providing a lead frame comprising a first lead having a first recess in a bottom surface and a second lead having a second recess in a bottom surface, placing a LED die over a top surface of at least one of the first and the second leads, electrically connecting the LED die to the first lead and to the second lead, forming a package around the LED die, the first lead and the second lead, the package having an opening in its upper surface exposing at least the LED die, and separating the package containing the LED die, the first lead and the second lead from the lead frame such that the package contains a first castellation and a second castellation in a side surface of the package, wherein the first castellation exposes at least one of the first lead and a first platable metal which is electrically connected to the first lead, the second castellation exposes at least one of the second lead and a second platable metal which is electrically connected to the second lead.

Further embodiments include methods of packaging a light emitting diode (LED) that include providing a lead frame comprising a first lead and a second lead, placing a LED die over a top surface of at least one of the first and the second leads, electrically connecting the LED die to the first lead and to the second lead, forming a package around the LED die, the first lead and the second lead, the package having an opening in its upper surface exposing at least the LED die, and separating the package containing the LED die, the first lead and the second lead from the lead frame, wherein the lead frame contains a first alignment mark and the package contains a second alignment mark.

Further embodiments include methods of packaging light emitting diodes (LEDs) that include bonding a plurality of LED die over a plurality of leads of a lead frame, electrically connecting each of the plurality of LED die to a respective two of the plurality of leads, dipping the lead frame into a

2

mold containing a moldable material, solidifying the moldable material to form a panel comprising a plurality of moldable material packages attached to the lead frame, wherein each of the plurality of packages is located around at least one of the plurality of LED dies electrically connected to the respective two of the plurality of leads, attaching a first set of the plurality of packages to a dicing tape, and singulating the first set of the plurality of packages from the panel.

Further embodiments include methods of testing a packaged light emitting diode (LED) that include providing a package containing a LED die which is electrically connected to a first lead and to a second lead located in the package, wherein the LED die is located over a top surface of at least one of the first and the second leads, attaching a bottom surface of the package to dicing tape such that a first recess is located in a bottom surface of the first lead exposed in the bottom surface of the package and a second recess is located in a bottom surface of the second lead exposed in the bottom surface of the package, and testing the LED die by poking a testing pin or needle through the dicing tape into at least one of the first recess and the second recess.

Various embodiments include packaged light emitting diode (LED) devices that include a first lead having a first recess in a bottom surface, a second lead having a second recess in a bottom surface, a LED die located over a top surface of at least one of the first and the second leads and electrically connected to the first lead and to the second lead, and a package located around the LED die, the first lead and the second lead, wherein the package contains an opening in its upper surface exposing at least the LED die, and the package contains a first castellation and a second castellation in a side surface of the package, the first castellation exposes at least one of the first lead and a first platable metal which is electrically connected to the first lead, and the second castellation exposes at least one of the second lead and a second platable metal which is electrically connected to the second lead.

Further embodiments include packaged light emitting diode (LED) devices that include a first lead having a first recess in a bottom surface, a second lead having a second recess in a bottom surface, a LED die located over a top surface of at least one of the first and the second leads and electrically connected to the first lead and to the second lead, a package located around the LED die, the first lead and the second lead, and wherein a sidewall of the package has a non-uniform thickness and contains at least one structural strength enhancing region of increased thickness.

Further embodiments include packaged light emitting diode (LED) devices that include a first lead having a first recess in a bottom surface, a second lead having a second recess in a bottom surface, a LED die located over a top surface of at least one of the first and the second leads and electrically connected to the first lead and to the second lead, a package located around the LED die, the first lead and the second lead, and wherein sides and ends of the first and the second leads are etched to increase a surface area of the first and the second leads.

Further embodiments include a lead frame including a frame connected to a plurality of electrically conductive leads, wherein at least one of the plurality of leads comprises a floating finger lead which contains at least one free hanging, cantilevered end which is not attached to the frame.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate

example embodiments of the invention, and together with the general description given above and the detailed description given below, serve to explain the features of the invention.

FIG. 1 is a schematic perspective illustration of a packaged LED device according to an embodiment.

FIG. 2A illustrates the packaged LED device mounted in a top-emitting configuration.

FIG. 2B illustrates the packaged LED device mounted in a side-emitting configuration.

FIG. 3A illustrates a packaged LED device according to one embodiment in which the package includes multiple LED dies and an interior wall separating a first compartment containing the at least one first LED die from a second compartment containing at least one second LED die.

FIG. 3B illustrates a packaged LED device according to another embodiment in which a sidewall of the package has a non-uniform thickness and contains structural strength enhancing regions of increased thickness.

FIG. 3C illustrates a packaged LED device according to another embodiment in which the package includes multiple LED dies and an interior wall separating a first compartment containing a green emitting LED die and a first encapsulant containing a green phosphor located over the green emitting LED die from a second compartment containing a red emitting LED die and a blue emitting LED die and a second encapsulant which lacks the green phosphor located over the red emitting LED die and the blue emitting LED die.

FIG. 3D illustrates a packaged LED device according to another embodiment in which the package includes multiple LED dies and two interior walls defining three separate compartments, where each compartment contains at least one LED die.

FIG. 4A illustrates a portion of a lead frame according to one embodiment in which the respective leads contain non-uniform recesses for forming castellations having varying widths and sides and ends of the leads are etched to increase a surface area of the leads.

FIG. 4B illustrates a portion of a lead frame that includes floating finger leads which contain at least one free hanging, cantilevered end which is not attached to the frame.

FIGS. 5A-D illustrate a method of packaging an LED die with a plurality of leads and a package according to one embodiment.

FIG. 6 illustrates a lead frame having a plurality of molded packages attached thereto and having alignment marks to facilitate separation of individual LED packages.

FIG. 7 schematically illustrates a method of testing an LED package using a testing pin according to one embodiment.

DETAILED DESCRIPTION

The various embodiments will be described with reference to the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts. References made to particular examples and implementations are for illustrative purposes, and are not intended to limit the scope of the invention or the claims.

Embodiments of the invention include packaged LED devices and methods of packaging an LED. In various embodiments, a package and lead design includes features that enable the packaged LED device to be mounted as either a top-emitting or a side-emitting LED package.

FIG. 1 is a schematic perspective illustration of a packaged LED device 100 according to one embodiment. The packaged LED device 100 includes a plurality of leads, including a first lead 101 and a second lead 103. Each lead 101, 103 may be

formed of an electrically conductive material (e.g., a metal, such as copper). The leads 101, 103 may be formed as part of a lead frame and separated from the frame to produce individual packaged LED devices 100, as described below. The leads 101, 103 may extend generally parallel without contacting one another between a first side surface 108 and a second side surface 109 of the device 100.

At least one LED die 105 (e.g., chip) may be mounted on a first surface 102 of lead 101. The LED die 105 may include one or more light-emitting semiconductor elements on a supporting substrate. Any suitable LED structure may be utilized. In embodiments, the LED may be a nanowire-based LED. Nanowire LEDs are typically based on one or more pn- or pin-junctions. Each nanowire may comprise a first conductivity type (e.g., doped n-type) nanowire core and an enclosing second conductivity type (e.g., doped p-type) shell for forming a pn or pin junction that in operation provides an active region for light generation. An intermediate active region between the core and shell may comprise a single intrinsic or lightly doped (e.g., doping level below 10^{16} cm^{-3}) semiconductor layer or one or more quantum wells, such as 3-10 quantum wells comprising a plurality of semiconductor layers of different band gaps. Nanowires are typically arranged in arrays comprising hundreds, thousands, tens of thousands, or more, of nanowires side by side on the supporting substrate to form the LED structure. The nanowires may comprise a variety of semiconductor materials, such as III-V semiconductors and/or III-nitride semiconductors, and suitable materials include, without limitation GaAs, InAs, Ge, ZnO, InN, GaInN, GaN, AlGaInN, BN, InP, InAsP, GaInP, InGaP:Si, InGaP:Zn, GaInAs, AlInP, GaAlInP, GaAlInAsP, GaInSb, InSb, AN, GaP and Si. The supporting substrate may include, without limitation, III-V or II-VI semiconductors, Si, Ge, Al_2O_3 , SiC, Quartz and glass. Further details regarding nanowire LEDs and methods of fabrication are discussed, for example, in U.S. Pat. Nos. 7,396,696, 7,335,908 and 7,829,443, PCT Publication Nos. WO2010014032, WO2008048704 and WO2007102781, and in Swedish patent application SE 1050700-2, all of which are incorporated by reference in their entirety herein. Alternatively, bulk (i.e., planar layer type) LEDs may be used instead of or in addition to the nanowire LEDs.

The LED die 105 may be mounted to the first surface 102 of the lead 101 using any suitable bonding technique. In embodiments, the surface of the LED die 105 may be electrically insulated from the lead 101 via an insulating material (e.g., a sapphire layer), which may be or may form part of the support substrate of the die 105. The active region of the LED die 105 may be electrically connected to the first lead 101 by a first wire 119, which may be bonded to a first bond pad region of the die 105. A second wire 121 may be bonded to a second bond pad region of the die 105 to electrically connect the die 105 to the second lead 103.

The packaged LED device 100 also includes a package 107, which may be a protective mold around the die 105 and leads 101, 103. For clarity, the package 107 is shown as transparent in FIG. 1. In embodiments, the package 107 may be a molded epoxy material, although other materials (e.g., ceramic, plastic, glass, etc.) may be utilized. The leads 101, 103 may be at least partially embedded in the package 107. As shown in FIG. 1, the package 107 may form the sidewalls and at least a portion of the bottom surface of the device 100 and may include an opening 111 in its upper surface exposing at least the LED die 105. In some embodiments, the opening 111 may be filled with an encapsulant material (not shown) that is

optically transmissive over at least a selected wavelength range. The encapsulant may comprise a phosphor or dye material.

The leads **101**, **103** may each include a recessed portion **112**, **114** on a bottom surface of the respective leads **101**, **103** (i.e., on the surface opposite the LED die **105**). The package **107** may include a first castellation **113** and a second castellation **115** in a side surface **110** of the package **107**. The first castellation **113** exposes an edge of the first lead **101** including the recessed portion **112**. The second castellation **115** exposes an edge of the second lead **103** including the recessed portion **114**. Each of the recessed portions **112**, **114** may include a filler material **117**, which may be a platable metal formed over the recessed portions **112**, **114**. Thus, in an embodiment, the first castellation **113** exposes an edge of the first lead **101** and platable metal **117**, and the second castellation **115** exposes an edge of the second lead **103** and the platable metal **117**.

In the embodiment of FIG. 1, the leads **101**, **103** have non-uniform dimensions along their length between the first end **108** and the second end **109** of the device **100**. As shown in FIG. 1, the cross-sectional dimensions of the leads **101**, **103** are identical proximate the first end **108**, including in the portions containing the respective recessed portions **112**, **114**, but are different proximate to the second end **108** of the device. The first lead **101** has an “L” shape in which the width of the lead **101** increases to accommodate the LED die **105**. The second lead **103** is widest proximate to the first end **108**, and narrows proximate to the second end **109**. Various other configurations are possible, including where the leads **101**, **103** have identical shapes along their entire lengths. Preferably, the LED die **105** is bonded to only to the top surface **102** of a rear portion of the first lead **101**, the first recess **112** is located in the bottom surface in a front portion of the first lead **101** which is different from the rear portion of the first lead, and the second recess **114** is located in the bottom surface in a front portion of the second lead **103** which is wider than rear portion of the second lead.

The packaged LED device **100** may be mounted to a support surface **200** in either a top-emitting or a side-emitting configuration, as shown in FIGS. 2A-B. FIG. 2A shows the device **100** in a top-emitting configuration, with the predominant direction of light emission from the LED indicated by the vertical arrow. At least a portion of the leads **101**, **103**, including at least the recessed portions **112**, **114**, may be exposed on the bottom surface of the package **107**. Electrical contacts **201** located over the support surface **200** may contact the exposed portions of the respective leads **101**, **103** to connect the leads **101**, **103** and the LED die **105** to an external current/voltage source. In embodiments, the electrical contacts **201** may be bonded to the leads **101**, **103**, such as via soldering. In some embodiments, the electrical contacts **201** may be soldered to the optional filler material **117** that may be located within the recessed portions **112**, **114** of the leads **101**, **103**.

FIG. 2B shows the device **100** in a side-emitting configuration, in which the side surface **110** of the package **107** containing the castellations **113**, **115** (see FIG. 1) faces the support structure **200** and the predominant direction of light emission (as indicated by the arrow) is parallel to the support surface **200**. In this configuration, the electrical contacts **201** on the support structure **200** (not visible in this view) contact the first and second leads **101**, **103** through the first and second castellations **113**, **115**, respectively. As in the embodiment of FIG. 2A, the electrical contacts **201** may be bonded (e.g., soldered) to the leads, either directly or indirectly

through the optional filler material. The side-emitting configuration of FIG. 2B may provide improved coupling of light into a waveguide.

The embodiment of FIG. 1 illustrates a package for a single LED die. In other embodiments, multiple LED dies may be included within a package. FIG. 3A illustrates an embodiment of a packaged LED device **300** in which the package **307** includes multiple LED dies **305a**, **305b**, **305c** and an interior wall **313** separating a first compartment **311** containing LED dies **305a**, **305b** from a second compartment **312** containing LED die **305c**. Each of the LED dies **305a**, **305b**, **305c** may be configured to emit light at different wavelengths (e.g., green, blue and red visible light). The packaged LED device **300** may include a plurality of leads **320**, **321**, **322**, **323**, **324**, **325**, each having a recessed portion as described above in connection with FIG. 1. Each of the dies **305a**, **305b**, **305c** may be mounted on a top surface of a lead and electrically connected to at least two different leads, as described above. The package **307** may include castellations **330**, **331**, **332**, **333**, **334**, **335**, **336** on a side surface **310** of the package **307** that expose the edges of the leads **320**, **321**, **322**, **323**, **324**, **325** at their respective recessed portions.

In one embodiment, the interior wall **313** may separate the second compartment **312** containing a red-emitting LED die **305c** from the first compartment **311** containing a green-emitting LED die **305a** and a blue-emitting LED die **305b**. The second compartment **312** may contain a first encapsulant (not shown) containing a red emitting phosphor located over the red LED die **305c**, and the first compartment **311** may contain a second encapsulant (not shown) which lacks the red emitting phosphor located over the green-emitting LED die **305a** and the blue-emitting LED die **305b**. Each die may contain nanowire and/or bulk LEDs. For example, the green emitting die **305a** may comprise nanowire LEDs, the red emitting die **305c** may comprise bulk LEDs, and the blue emitting die **305b** may comprise either nanowire or bulk LEDs.

FIG. 3B illustrates an alternative embodiment of the packaged LED device **300** in which the package **307** includes a variable wall thickness and an internal radius to add wall thickness in select areas and thus increase the package structural strength, such as a structural strength enhancing region **314** of increased thickness in a sidewall of the package. FIG. 3B also illustrates castellations **330**, **331**, **332**, **333**, **334**, **335** and leads **320**, **321**, **322**, **323**, **324**, **325** having varying dimensions (e.g., at castellation **330** and lead **320** are wider than the other castellations and leads in the device **300**).

FIG. 3C illustrates another embodiment of a packaged LED device **300**. The device **300** may be similar to the device of FIG. 3A, but in this embodiment, the second compartment **312** separated by the interior wall **313** contains a green-emitting LED die **305a**, and the first compartment **311** contains a blue-emitting LED die **305b** and a red-emitting LED die **305c**. The second compartment **312** may contain a first encapsulant (not shown) containing a green-emitting phosphor located over the green-emitting LED die **305a**, and the first compartment **311** may contain a second encapsulant (not shown) which lacks the green emitting phosphor over the blue-emitting LED die **305a** and the red-emitting LED die **305c**. Each die may contain nanowire and/or bulk LEDs. In addition, the LED device **300** of FIG. 3C may include a variable wall thickness and internal radius to enhance structural strength and/or castellations **330**, **331**, **332**, **333**, **334**, **335** having varying dimensions such as shown in FIG. 3B.

FIG. 3D illustrates yet another embodiment of a packaged LED device. The device **300** may be similar to the devices shown in FIGS. 3A and 3C, but may include two interior walls

313a, 313b that separate the device **300** into three compartments **311, 312, 340**. Each compartment **311, 312, 340** may contain at least one LED die **305a, 305b, 305c**. For example, compartment **340** may contain a first one of a blue-emitting LED die **305b**, a green-emitting LED die **305a**, and a red-emitting LED die **305c** (e.g., compartment **340** contains a blue-emitting LED die **305b** in FIG. 3D), compartment **311** may contain a second one of the blue-emitting LED die **305b**, the green-emitting LED die **305a** and the red-emitting LED die **305c** (e.g., compartment **311** contains a green-emitting LED die **305a** in FIG. 3D), and compartment **312** may contain a third one of the blue-emitting LED die **305b**, the green-emitting LED die **305a** and the red-emitting LED die **305c** (e.g., compartment **312** contains a red-emitting LED die **305c** in FIG. 3D).

Each compartment **311, 312, 340** may contain an encapsulant (not shown) over the respective LED dies **305a, 305b, 305c**. The encapsulant in each compartment **311, 312, 340** may be the same as or different than the encapsulant in the other compartments. In one embodiment, compartment **312** may contain a first encapsulant (not shown) containing a red emitting phosphor located over the red LED die **305c**, compartment **311** may contain a second encapsulant (not shown) which lacks the red emitting phosphor located over the green-emitting LED die **305a**, and compartment **340** may contain a third encapsulant (not shown) which lacks the red emitting phosphor located over the blue-emitting LED die **305b**. The second encapsulant and the third encapsulant may be the same material or different materials.

In another embodiment, compartment **311** may contain a first encapsulant (not shown) containing a green emitting phosphor located over the green LED die **305a**, compartment **312** may contain a second encapsulant (not shown) which lacks the green-emitting phosphor located over the red-emitting LED die **305c**, and compartment **340** may contain a third encapsulant (not shown) which lacks the green-emitting phosphor located over the blue-emitting LED die **305b**. The second encapsulant and the third encapsulant may be the same material or different materials in this embodiment.

In yet another embodiment, compartment **311** may contain a first encapsulant (not shown) containing a green emitting phosphor located over the green LED die **305a**, compartment **312** may contain a second encapsulant (not shown) containing a red emitting phosphor located over the red LED die **305c**, and compartment **340** may contain a third encapsulant (not shown) which lacks the green-emitting phosphor and the red-emitting phosphor located over the blue-emitting LED die **305b**.

Each die in the respective compartments **311, 312, 340** may contain nanowire and/or bulk LEDs. Further, a packaged LED device **300** may include additional interior walls that separate the device into more than three compartments. In addition, the LED device **300** of FIG. 3D may include a variable wall thickness and internal radius to enhance structural strength and/or castellations **330, 331, 332, 333, 334, 335** having varying dimensions such as shown in FIG. 3B.

FIG. 4A is a schematic top (overhead) view of a lead frame **400** having a plurality of leads **401, 402, 403, 404, 405, 406** used for producing a packaged LED device, such as device **300**. The lead frame **400** may be formed, for example, by patterning (e.g., etching) a copper sheet or plate to form the frame **400** and leads **401, 402, 403, 404, 405, 406** in a desired shape. Pits (i.e., recesses) **411, 412, 413, 414, 415, 416** may be formed in a surface of the leads **401, 402, 403, 404, 405, 406** to provide the recessed portions. The sides **408** and ends **409** of the leads **401, 402, 403, 404, 405, 406** may be etched to increase a surface area for the package material (e.g.,

epoxy) to mate with and thus improve the adhesion of the leads to the package. The leads may be removed from the frame **400** to produce a packaged LED device, as described further below.

FIG. 4B illustrates an alternative embodiment of a lead frame **400** having one or more “floating finger” leads **440** (i.e. a protrusion or finger that is not supported at both ends, e.g., which contains at least one free hanging, cantilevered end which is not attached to the frame). The floating finger lead frame may be made significantly wider to support it. The floating fingers allow for independent electrical connections inside the package after the leads are singulated (i.e., removed from the frame **400**).

FIGS. 5A-D illustrate a method of packaging an LED die according to one embodiment. The method may include forming pits (i.e., recesses) **501, 503** in the back side of the respective leads **101, 103** of a lead frame, as shown in FIG. 5A. The leads frame having leads or “fingers” may be as shown in FIGS. 4A-B, for example. The leads **101, 103** are illustrated as rectangles for simplicity in FIG. 5A-D, although other shapes may be used. In addition, the frame that connects the leads **101, 103** is not illustrated for clarity.

A metal filler **117** (e.g., a solderable metallization stack up) may be formed in the pits **501, 503**, as shown in FIG. 5B. An LED die **105** may be bonded to the top surface of one or both leads **101, 103**, as shown in FIG. 5C. The LED die **105** may be electrically connected to the leads **101, 103** by wires. The leads **101, 103** and LED die **105** may then be encapsulated by a package **107**, which may be an epoxy material. The package **107** includes an opening **111** in its upper surface exposing at least the LED die **105**.

In embodiments, the package **107** may be formed by dipping a lead frame containing the leads **101, 103** and LED die(s) **105** into a mold containing an epoxy and solidifying the epoxy to form the package attached to the lead frame. Alternatively, the die **105** may be attached to the leads **101, 103** after the formation of the package **107** on the leads **101, 103**. Thus, the LED die **105** may be electrically connected to the first lead and to the second lead by wire bonding the LED die to the first lead and to the second lead before or after the step of forming the package. A plurality of packages **107**, each encapsulating a plurality of lead frame leads and one or more LED dies, may be formed over a lead frame **400** to form a panel **600** of packaged LEDs, as shown in FIG. 6. In embodiments, the molded panel **600** may have alignment marks (e.g., dicing lines) molded into the surface of the epoxy package walls. Similar marks, such as etched lines or slots, may be included in the lead frame **400**. These features may facilitate inspection to check that the molded epoxy panel is aligned to the lead frame within specified tolerances. In addition, the alignment marks may aid a dicing operator in aligning a dicing saw blade to the panel and for quality assurance to check after dicing that the diced package walls are within tolerance. Thus, the singulation step may optionally include checking that a first alignment mark on the lead frame and a second alignment mark on the package (or on the panel) are within a predetermined tolerance, and aligning a dicing saw blade with the first alignment mark and the second alignment mark before dicing the package from the lead frame.

FIG. 5C illustrates a dicing line **507** in the epoxy package **107**. The dicing line **507** may be aligned over the pits **501, 503** in the respective leads **101, 103** of the lead frame. The package **107** containing the LED die **105**, the first lead **101** and the second lead **103** may then be separated from the lead frame, as shown in FIG. 5C. Separating the package **107** from the lead frame may include dicing or snapping the package along the dicing line **507** and through the pits **501, 503** to expose a

first castellation 113 and a second castellation 115 in the side surface of the package 107. Dicing or otherwise separating the package 107 through the pits 501, 503 exposes the recessed portions 112, 114 of the leads 101, 103, as well as the filler material (e.g., solderable metal) which partially fills the pits.

In embodiments, a dicing tape 700 may be bonded to the bottom surface of the package 107, prior to separating the package 107 from the lead frame (i.e., singulation), as shown in FIG. 7. The LED die 105 may be tested by poking a testing pin 701 or needle through the dicing tape 700 in the area of the pits 501, 503. The pits 501, 503 allow the tape 700 to stretch and the pin 701 to break through the tape to contact the leads 101, 103. The pin 701 may form a temporary electrical connection with the LED device to enable testing. This action of punching through tape instead of crushing or pinching has the added advantage that the probe tip is wiped clean and thus avoids clogging of the probe needle.

The foregoing method descriptions are provided merely as illustrative examples and are not intended to require or imply that the steps of the various embodiments must be performed in the order presented. As will be appreciated by one of skill in the art the order of steps in the foregoing embodiments may be performed in any order. Words such as “thereafter,” “then,” “next,” etc. are not necessarily intended to limit the order of the steps; these words may be used to guide the reader through the description of the methods. Further, any reference to claim elements in the singular, for example, using the articles “a,” “an” or “the” is not to be construed as limiting the element to the singular.

Although the foregoing refers to particular preferred embodiments, it will be understood that the invention is not so limited. It will occur to those of ordinary skill in the art that various modifications may be made to the disclosed embodiments and that such modifications are intended to be within the scope of the invention. All of the publications, patent applications and patents cited herein are incorporated herein by reference in their entirety.

What is claimed is:

1. A method of packaging a light emitting diode (LED), comprising:

providing a lead frame comprising a first lead having a first recess in a bottom surface and a second lead having a second recess in a bottom surface;
placing a LED die over a top surface of at least one of the first and the second leads;
electrically connecting the LED die to the first lead and to the second lead;
forming a package around the LED die, the first lead and the second lead, the package having an upper surface, a bottom surface, at least one first side surface extending between the upper surface and the bottom surface and an opening in the upper surface exposing at least the LED die; and

separating the package containing the LED die, the first lead and the second lead from the lead frame such that the package contains a first castellation and a second castellation in the first side surface of the package;

wherein:

- (i) the first castellation exposes at least one of the first lead and a first platable metal which is electrically connected to the first lead;
- (ii) the second castellation exposes at least one of the second lead and a second platable metal which is electrically connected to the second lead;
- (iii) the LED die comprises at least one green emitting LED die;

(iv) the package further comprises:

a third lead, a fourth lead, a fifth lead and a sixth lead;
a third castellation in the first side surface of the package, wherein the third castellation exposes at least one of the third lead and a third platable metal which is electrically connected to the third lead;

a fourth castellation in the first side surface of the package, wherein the fourth castellation exposes at least one of the fourth lead and a fourth platable metal which is electrically connected to the fourth lead;

a fifth castellation in the first side surface of the package, wherein the fifth castellation exposes at least one of the fifth lead and a fifth platable metal which is electrically connected to the fifth lead;

a sixth castellation in the first side surface of the package, wherein the sixth castellation exposes at least one of the sixth lead and a sixth platable metal which is electrically connected to the sixth lead;

at least one blue emitting LED die which is electrically connected to the third lead and to the fourth lead; and

at least one red emitting LED die which is electrically connected to the fifth lead and to the sixth lead;

(v) the package comprises an interior wall separating a first compartment containing the at least one green emitting LED die from a second compartment containing the at least one red emitting LED die and the at least one blue LED die;

(vi) the first compartment contains a first encapsulant containing a green emitting phosphor located over the at least one green emitting LED die; and

(vii) the second compartment contains a second encapsulant which lacks the green emitting phosphor located over the at least one red emitting LED die and the at least one blue emitting LED die.

2. A method of packaging a light emitting diode (LED), comprising:

providing a lead frame comprising a first lead having a first recess in a bottom surface and a second lead having a second recess in a bottom surface;

placing a LED die over a top surface of at least one of the first and the second leads;

electrically connecting the LED die to the first lead and to the second lead;

forming a package around the LED die, the first lead and the second lead, the package having an upper surface, a bottom surface, at least one first side surface extending between the upper surface and the bottom surface and an opening in the upper surface exposing at least the LED die; and

separating the package containing the LED die, the first lead and the second lead from the lead frame such that the package contains a first castellation and a second castellation in the first side surface of the package;

wherein:

(i) the first castellation exposes at least one of the first lead and a first platable metal which is electrically connected to the first lead;

(ii) the second castellation exposes at least one of the second lead and a second platable metal which is electrically connected to the second lead;

(iii) the LED die comprises at least one green emitting LED die;

(iv) the package further comprises:

a third lead, a fourth lead, a fifth lead and a sixth lead;

11

- a third castellation in the first side surface of the package, wherein the third castellation exposes at least one of the third lead and a third platable metal which is electrically connected to the third lead;
 - a fourth castellation in the first side surface of the package, wherein the fourth castellation exposes at least one of the fourth lead and a fourth platable metal which is electrically connected to the fourth lead;
 - a fifth castellation in the first side surface of the package, wherein the fifth castellation exposes at least one of the fifth lead and a fifth platable metal which is electrically connected to the fifth lead;
 - a sixth castellation in the first side surface of the package, wherein the sixth castellation exposes at least one of the sixth lead and a sixth platable metal which is electrically connected to the sixth lead;
 - at least one blue emitting LED die which is electrically connected to the third lead and to the fourth lead; and
 - at least one red emitting LED die which is electrically connected to the fifth lead and to the sixth lead; and
 - (v) the package comprises at least two interior walls defining at least three separate compartments, wherein the at least one green emitting LED die is located in a first compartment, the at least one red emitting LED die is located in a second compartment and the at least one blue emitting LED die is located in a third compartment.
3. The method of claim 2, wherein:
- the first compartment contains a first encapsulant containing a green emitting phosphor located over the at least one green emitting LED die;
 - the second compartment contains a second encapsulant which lacks the green emitting phosphor located over the at least one red emitting LED die; and
 - the third compartment contains a third encapsulant which lacks the green emitting phosphor located over the at least one blue emitting LED die.
4. The method of claim 3, wherein the second encapsulant and the third encapsulant comprise the same material.
5. The method of claim 3, wherein the second encapsulant contains a red emitting phosphor, and the third encapsulant lacks the green emitting phosphor and the red emitting phosphor.
6. The method of claim 2, wherein:
- the second compartment contains a second encapsulant containing a red emitting phosphor located over the at least one red emitting LED die; and
 - the first compartment and the third compartment contain a first and third encapsulant, respectively, where the first and the third encapsulant lack the red emitting phosphor.
7. A packaged light emitting diode (LED) device, comprising:
- a first lead having a first recess in a bottom surface;
 - a second lead having a second recess in a bottom surface;
 - a LED die located over a top surface of at least one of the first and the second leads and electrically connected to the first lead and to the second lead; and
 - a package located around the LED die, the first lead and the second lead;
- wherein:
- (i) the package contains an upper surface, a bottom surface, at least one first side surface extending between the upper surface and the bottom surface and an opening in the upper surface exposing at least the LED die;

12

- (ii) the package contains a first castellation and a second castellation in the first side surface of the package;
 - (iii) the first castellation exposes at least one of the first lead and a first platable metal which is electrically connected to the first lead;
 - (iv) the second castellation exposes at least one of the second lead and a second platable metal which is electrically connected to the second lead;
 - (v) the package further comprises:
 - a third lead, a fourth lead, a fifth lead and a sixth lead;
 - a third castellation in the first side surface of the package, wherein the third castellation exposes at least one of the third lead and a third platable metal which is electrically connected to the third lead;
 - a fourth castellation in the first side surface of the package, wherein the fourth castellation exposes at least one of the fourth lead and a fourth platable metal which is electrically connected to the fourth lead;
 - a fifth castellation in the first side surface of the package, wherein the fifth castellation exposes at least one of the fifth lead and a fifth platable metal which is electrically connected to the fifth lead;
 - a sixth castellation in the first side surface of the package, wherein the sixth castellation exposes at least one of the sixth lead and a sixth platable metal which is electrically connected to the sixth lead;
 - at least one blue emitting LED die which is electrically connected to the third lead and to the fourth lead; and
 - at least one red emitting LED die which is electrically connected to the fifth lead and to the sixth lead;
 - (vi) the package comprises an interior wall separating a first compartment containing the at least one green emitting LED die from a second compartment containing the at least one red emitting LED die and the at least one blue LED die;
 - (vii) the first compartment contains a first encapsulant containing a green emitting phosphor located over the at least one green emitting LED die; and
 - (viii) the second compartment contains a second encapsulant which lacks the green emitting phosphor located over the at least one red emitting LED die and the at least one blue emitting LED die.
8. A packaged light emitting diode (LED) device, comprising:
- a first lead having a first recess in a bottom surface;
 - a second lead having a second recess in a bottom surface;
 - a LED die located over a top surface of at least one of the first and the second leads and electrically connected to the first lead and to the second lead; and
 - a package located around the LED die, the first lead and the second lead;
- wherein:
- (i) the package contains an upper surface, a bottom surface, at least one first side surface extending between the upper surface and the bottom surface and an opening in the upper surface exposing at least the LED die;
 - (ii) the package contains a first castellation and a second castellation in the first side surface of the package;
 - (iii) the first castellation exposes at least one of the first lead and a first platable metal which is electrically connected to the first lead;
 - (iv) the second castellation exposes at least one of the second lead and a second platable metal which is electrically connected to the second lead;
 - (v) the package further comprises:

13

a third lead, a fourth lead, a fifth lead and a sixth lead;
 a third castellation in the first side surface of the package, wherein the third castellation exposes at least one of the third lead and a third platable metal which is electrically connected to the third lead;
 a fourth castellation in the first side surface of the package, wherein the fourth castellation exposes at least one of the fourth lead and a fourth platable metal which is electrically connected to the fourth lead;
 a fifth castellation in the first side surface of the package, wherein the fifth castellation exposes at least one of the fifth lead and a fifth platable metal which is electrically connected to the fifth lead;
 a sixth castellation in the first side surface of the package, wherein the sixth castellation exposes at least one of the sixth lead and a sixth platable metal which is electrically connected to the sixth lead;
 at least one blue emitting LED die which is electrically connected to the third lead and to the fourth lead; and
 at least one red emitting LED die which is electrically connected to the fifth lead and to the sixth lead; and
 (vi) the package comprises at least two interior walls defining at least three separate compartments, wherein the at least one green emitting LED die is located in a first compartment, the at least one red emitting LED die is located in a second compartment and the at least one blue emitting LED die is located in a third compartment.

9. The device of claim 8, wherein:
 the first compartment contains a first encapsulant containing a green emitting phosphor located over the at least one green emitting LED die;
 the second compartment contains a second encapsulant which lacks the green emitting phosphor located over the at least one red emitting LED die; and
 the third compartment contains a third encapsulant which lacks the green emitting phosphor located over the at least one blue emitting LED die.

14

10. The device of claim 9, wherein the second encapsulant and the third encapsulant comprise the same material.

11. The device of claim 9, wherein the second encapsulant contains a red emitting phosphor, and the third encapsulant lacks the green emitting phosphor and the red emitting phosphor.

12. The device of claim 8, wherein:
 the second compartment contains a second encapsulant containing a red emitting phosphor located over the at least one red emitting LED die; and
 the first compartment and the third compartment contain a first and third encapsulant, respectively, where the first and the third encapsulant lack the red emitting phosphor.

13. The device of claim 8, wherein:
 the package further has second, third and fourth side surfaces extending between the upper surface and the bottom surface; and
 no castellations are located in the second, third and fourth side surfaces of the package.

14. The device of claim 7, wherein:
 the package further has second, third and fourth side surfaces extending between the upper surface and the bottom surface; and
 no castellations are located in the second, third and fourth side surfaces of the package.

15. The method of claim 1, wherein:
 the package further has second, third and fourth side surfaces extending between the upper surface and the bottom surface; and
 no castellations are located in the second, third and fourth side surfaces of the package.

16. The method of claim 2, wherein:
 the package further has second, third and fourth side surfaces extending between the upper surface and the bottom surface; and
 no castellations are located in the second, third and fourth side surfaces of the package.

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